A Breath of Fresh Technology

An innovative technique for measuring and visualizing the concentrations of air pollutants couples infrared optical remote sensing with computer-assisted tomography (CAT) to estimate human exposures more accurately. The method, which draws on technology traditionally reserved for medical CAT scanning, promises to outperform current devices for measuring emissions. Once perfected, the detection system, known as Remote Sensing Computed Tomography (RSCT), could be used to enhance workplace health and safety in industries such as petroleum refineries and synthetic organic chemical manufacturing facilities.

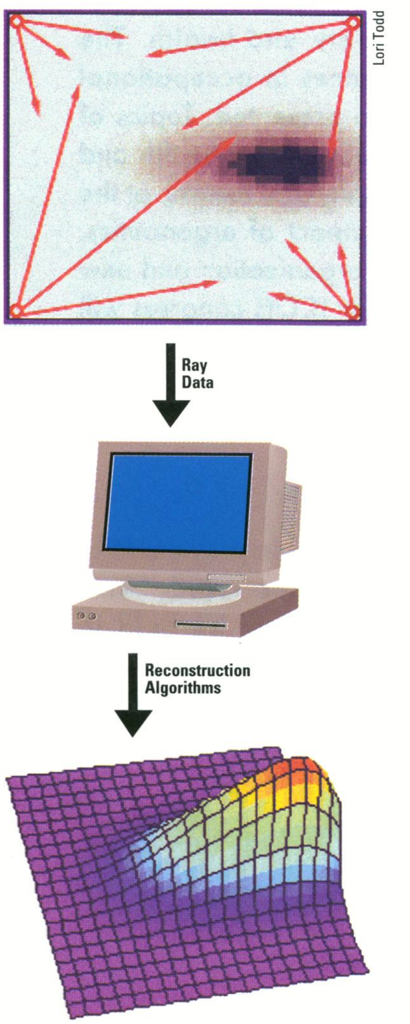
RSCT is the brainchild of Lori Todd, an assistant professor in the Department of Environmental Sciences and Engineering at the University of North Carolina at Chapel Hill. Todd and her research team are refining this technology, which uses multiple beams of infrared light to scan an indoor manufacturing area or outdoor industrial site for airborne pollutants, then creates two-dimensional computerized grids mapping the locations and concentrations of the pollutants.

"I adapted the concept of CAT scanning used in the medical field," says Todd. "Instead of shooting radiation at many angles through a body to view the organs, I am shooting a network of infrared beams through air at many angles to reconstruct [chemical] concentrations." RSCT can simultaneously measure over 100 different chemicals, whereas current detection methods are usually limited to a much smaller number.

Filling a Gap

As the former deputy chief of environmental toxicology in New York City's Department of Health, Todd was frequently called to inspect sites where workers complained of exposure to toxic chemicals. She found the detection equipment used for such assessments lacking: "I did air sampling and saw a need for something to give more reliable information about what people are exposed to," says Todd, who is a certified industrial hygienist.

The sampling method used in the 1980s is essentially the same in use today: technicians normally use hand-held instruments to pull contaminated air onto sampling media that must be sent to a laboratory where analysis of the pollutants can take more than a week. Time spent analyzing pollutants is one of several drawbacks to this method, according to Todd. In addition, technicians gather data from a limited number of fixed samples over an area (a room in a manufacturing plant where chemicals are processed, for example), which yields poor spatial resolution of the concentrations measured. And, since sample collection is integrated over time, the resulting data give poor temporal resolution of contaminant concentrations as well. "For ambient air, scientists are attempting to infer the nature, motion, and dispersion of pollutants, and validate numerical transport models using only this limited sampling data," Todd says.



Remote Sensing and Computed Tomography. Data from infrared scans are fed into a tomographic algorithm to create a two-dimensional map of chemical concentrations.

Another problem is that a limited number of measurements taken on a single day are used to estimate worker exposures. These measurements do not reflect day-to-day variability or account for the flow of contaminants, both of which strongly influence human exposure.

Todd says that she saw a gap to fill: "Nothing else could provide real-time measurements of multiple chemicals over large distances," Todd explains. Undeterred by the skepticism of some of her associates, Todd conducted a feasibility study of her idea while pursuing her doctorate in occupational health and computer science at UNC. Todd's novel ideas have since captured the attention of the petroleum and furniture manufacturing industries, the EPA, and the National Institute for Occupational Safety and Health. In 1994 the National Science Foundation named Todd a Presidential Faculty Fellow, placing her in an elite group of 15 top scientists. The honor, conferred by President Clinton, brought with it a $500,000 grant to UNC-Chapel Hill to further Todd's research.

Perfecting the Technology

Todd assembled a research team including a biomedical engineer and a full-time programmer to develop the optical remote sensing system. The system scans the air for pollutants, then produces a two-dimensional pollutant concentration map that is "spatially and temporally resolved over large outdoor areas or smaller indoor environments," Todd says. In a significant departure from current sampling technology, the remote sensors gather real-time measurements that provide a path-integrated concentration over an entire beam path, not at a single point.

Most of the team's work to date has been theoretical and experimental—either in computer simulations or in a greenhouselike university laboratory. The greenhouse chamber contains two open-path, broad-band Fourier transform infrared spectrometers (two of only four scanning FTIRs manufactured) on loan to Todd by the U.S. Department of Energy. FTIR pairs a light source and scanning detector with a retroflector placed opposite the area to be sampled. Retroflectors contain mirrors in a cubic design that reflect light directly back to the source. Using retroflectors helps to compensate for atmospheric shifts due to wind or temperature changes that could alter a reading of the pollutants in a given place.

Steve McCaw, Image Associates

Spotlight on pollutants. Lori Todd prepares to scan the air in her greenhouse test chamber.

Todd is trying to determine optimal placement of the remote sensing sources and detectors. "You need some kind of symmetry in placing the equipment," she explains. "You don't want to skew the results with equipment placement."

Once measurements have been gathered by the scanner, the data are fed into a tomographic algorithm that, within minutes, reconstructs a gridded, two-dimensional map showing chemical concentrations within the sampled area. Each map provides spatial chemical concentration data, while a series of maps generated from continuously gathered data provide temporal information as well, and could be used to visualize contaminant flow over time. Todd's team is currently trying to determine the minimum number of light beams necessary to construct an accurate map, in an attempt to keep the application cost effective.

When the researchers move their experiments to the field, they will also grapple with the problem of objects such as furnishings or other equipment that may obstruct the paths of light. Another difficulty is air's inherently dynamic qualities: unlike a medical CAT scan that analyzes an unmoving human body, RSCT scans for air toxics present in a constantly moving medium.

A New Alternative

The hand-held "sniffers" manufacturers and processors currently use to sample air are positioned at every possible seam, joint, valve, pipe flange, and pump to detect fugitive emissions, according to Rima Dishakjian, a chemist in the EPA's Emission Measurement Center in Research Triangle Park, North Carolina. Dishakjian is following Todd's research, which is partially funded by the EPA through a three-year cooperative agreement. "These random leaks in equipment contribute a lot to air pollution," Dishakjian says. A large chemical or petroleum processor may have "hundreds of thousands of potential leaky sources," she says. Thus, a more sophisticated measuring and imaging system may attract a large manufacturer for whom compliance and workplace safety monitoring is an ongoing task, although cost would also be a factor. According to Todd, the smaller RSCT instrument costs about $50,000, while the larger one costs nearly three times that amount.

According to Dishakjian, a couple of instruments set up on the perimeter of a process, for example, would be sufficient to track fugitive emissions in a given area. "You would get a quick response—continuously," she says. "Once the area is mapped, you would be able to pinpoint the source of a leak." Todd's system would also immediately reveal a major system breakdown or catastrophic leak, facilitating more timely worker evacuation.

"Todd's research is interesting; it bears following," says Howard Feldman, research program coordinator for the American Petroleum Institute in Washington, DC. However, he cautions, "the practical applicability remains to be proven."

Feldman agrees that remote sensing coupled with computer tomography would be desirable for refineries if research and testing prove it commercially viable. The API collaborated with Todd's team, the EPA, and several other consultants in a field test conducted earlier this year in Duke Forest, a privately owned reserve in Durham, North Carolina. "We're interested in examining the possibility of using remote sensing for measuring emissions from a volume source, for example, a single stack that [releases] emissions in three dimensions," says Feldman. In particular, he adds, "we were interested in examining how emissions from a volume source dispersed."

While continuing her work in the laboratory, Todd plans to do more field tests—this time in industrial facilities. This is one of the next steps to getting the technology to the marketplace, which, according to the EPA's Dishakjian, may happen in three to four years "assuming success at every stage." Even then, the system wouldn't completely replace current point-source sampling techniques, particularly as a tool for compliance monitoring under Clean Air Act guidelines, because compliance standards are tied to the sampling techniques currently in use. Todd's system would offer an attractive alternative. "First we would have to show equivalency of this technique to the original one," Dishakjian says. "Then, people would have a choice."

"Compliance is a hard field to change," Todd concedes. "It's hard to get new methods approved." Nevertheless, Todd says, an industrial hygienist could use the more sophisticated system to get better information about the type and location of chemicals in the workplace, which would ultimately lead to healthier environments, not to mention healthier workers.

Jennifer Medlin

Suggested Reading

Todd LA, Leith D. Remote sensing and computed tomography in industrial hygeine. Am Ind Hyg Assoc J 51:224–233 (1990).

Todd LA, Ramachandran G. Evaluation of optical source-detector configurations for tomographic reconstruction of concentrations in indoor air. Am Ind Hyg Assoc J 55: 1133–1143 (1994).

Todd LA, Ramachandran G. Evaluation of algorithms for tomographic reconstruction of chemicals in indoor air. Am Ind Hyg Assoc J 55: 403-417 (1994).